Major Hydraulic Systems in Algeria

Proceedings of the Second IWA Workshop on Evolution of Qanat
and Relevant Hydraulic Technologies, 8-10 november 2015. ICQHS-Yazd (Iran). 141-154

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Abstract

Algerian Sahara presents various traditional hydraulic systems. Some of them are important due to some major features such as geography, accuracy and collective organization. Three major water systems have been figured out; it is the foggara system surrounding the Tademait plateau, the artesian system of the Wadi-Righ valley at the east and, between them, the Mzab system around Ghardaia.

Both three systems are presented with their particular features and aspects through their geographical location, their hydrological and climatic conditions, and the way water is managed and how this affects the urban morphology and oasis features. Moreover, are underlined conditions of water flow accuracy and main concerns corresponding to each system. Comparing characteristics contributes to figure out to what extent the systems basic rules could explain relationships to the society and the environment.

People used to seek water following its modes of availability and eventually develop a local know how. Hydro geological conditions are thus relevant in the rise of various hydraulic systems. For centuries, these systems have been providing prosperous life in the Saharan oases. They contributed to develop knowledge, know-how and even a sustainable ecosystem.

Keywords

Hydraulic Systems; water Heritage; artesian system; foggara; Mzab wells; Algerian Sahara.

INTRODUCTION

The study of hydraulic systems is relevant to reinforce knowledge about ancient civilizations. This interest is more emphasized in the case of arid zones due to water scarcity. In Algeria, up to the discovery of oil and the Continental Intercalary aquifer in the Sahara, water used to be available for centuries by hydraulic systems well adapted to local geomorphology.

In Saharan territories, there was only irrigation based agriculture. Descriptions in old written sources are not accurate enough about hydraulic systems. The sole known written reference is given by Ibn-Khaldun (1856) describing how to dig artesian wells in Wadi-Righ region in 1341. However, regarding Herodotus (1889) description of Saharan territories since the Vth century BC and Rognon (1994) works attesting aridity for more than 4000 years, it is not so hard to conclude that irrigation based agriculture was quite present in the Sahara for more than 2500 years.

The Maghreb is composed of three major regions organized in successive layers. a thin coastal Mediterranean climate zone called the Sahel. It is limited by the chain of Tellian Atlas Mountains. The second is called the Highlands; it is situated in course between both Tellian and Saharan Atlas Mountains and characterized by a semi-arid climate. The third region is the Sahara in the southern side (Fig.1).

Algerian Sahara presents various traditional hydraulic systems. Some of them are quite identified to a geographical area and they require particular accuracy; hence they always present collective organization. It is the case of the systems based on foggara (Qanat), artesian wells and the Mzab region Dam-well system or the Mzab system. Each of these systems has

its particular geographical, hydrological and climatic characteristics. Both systems catch underground water except that the Mzab system use ground water to recharge the aquifer.

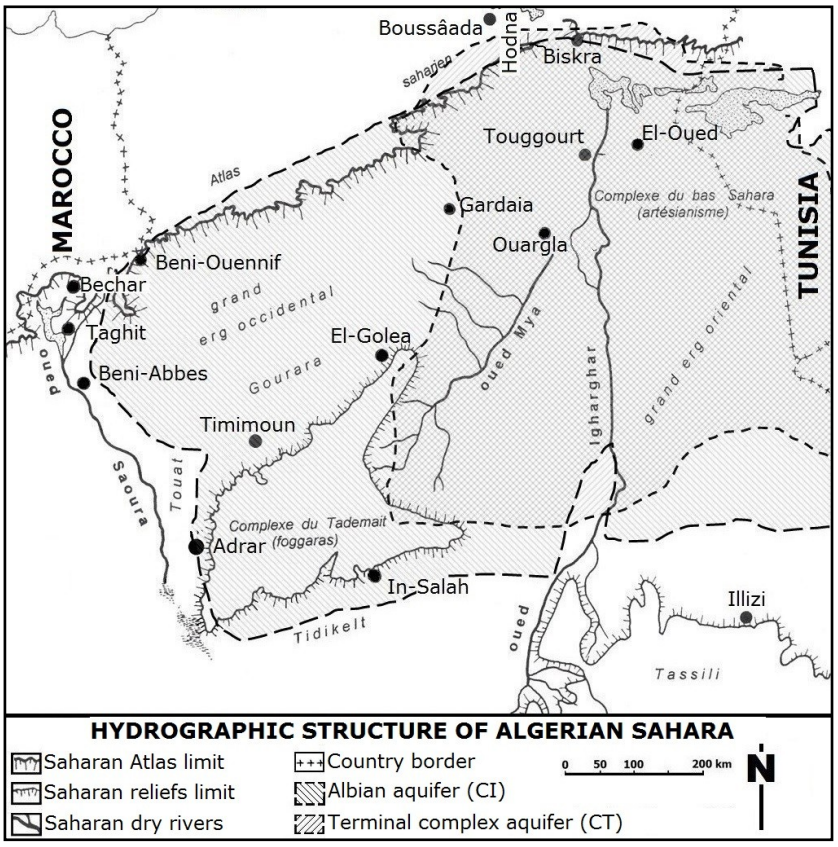

Fig. 1, Map of the Hydrographic structure of the Algerian Sahara, prepared from the Observatoire du Sahara et du Sahel [OSS] data.

The main focus of this work is to underline the genuine characteristics of each of the three major hydraulic systems. It is needed therefore to introduce them in their previous features before the advent of the recent changes, as they used to be exclusive in their own environment before the large introduction of modern hydraulic technology.

The French water interest in Algerian Sahara began soon they intend to occupy the Territory. Hydraulic studies grew up since then with the colonization process. Saharan territory domination began with the capture of Laghouat oasis in December 1852. Yet in 1851 Adrien Berbrugger (1862) was charged by the General Governor of Algeria to achieve within two years a broad investigation into the artesian structures in the northeast Sahara. In January 23rd 1896 the General Government of Algeria sent a statement to the county mayors to undertake a search about ancient hydraulic structures. The investigation has not led too much and it has been resumed by Stéphane Gsell (1902). The work was essentially about irrigated agriculture in North Algeria. Even though, it reached the region of Biskra, door of Eastern Sahara, and Wadi-Djedi valley. Additional prospection has also been undertaken in western areas (Flamand 1908).

By the beginning of the XXth century, the whole Sahara was already colonized except for Tindouf region in the extreme east (annexed in 1930). Some works have been achieved

classifying Saharan regions due to their hydraulic organization. The first hydrologic studies are of Rolland (1894) and Hähnel (1895) involving all the Maghreb morphology and hydrography. The works of Brunhes (1902) are dedicated to human geography and irrigation in both Iberian Peninsula and North Africa. Twenty-five years after, Moulias (1927) published his study on hydraulic organization of Saharan oases. Each of these studies is based on different criteria assessing hydraulic organization, geographic, hydrographic or legal criteria.

THE FOGGARA SYSTEM

The foggara is the equivalent of the qanat or kahrez in the Middle east. It has a Berber name « ifli ». The principle is to drain by gravity underground water to the surface of a lower soil. From this point begins water distribution. Foggaras are present in Algeria on the Western limits of the Albian aquifer. The three sub regions of Gourara, Tuat and Tidikelt are surrounding the Tademait plateau, a highland situated at the country middle as showed in figure 1. These regions have respectively for capital Timimoun, Adrar and In-Salah.

The foggara exists elsewhere following the southern boundaries of the Great Western Erg in north Gourara where water is supplied from the Erg aquifer. It used to be also in use on the southwest slopes of the Morrocan Great Atlas like in Beni-Ouennif and in the southwest valley like in Tabelbala and Tindouf. Small foggaras used to be dug in some river beds in the Hoggar region like in Tamanrasset and Abalessa in the Central Sahara.

Arround the Tademait plateau water is available only on the limit of the Albian aquifer where the water table becomes deepless. From Gourara to Tidikelt galleries draw curved lines around the Tademait plateau (Fig. 2). Hence the foggara territory is a linear space gathering successive layers from the highest to the lowest area: foggara galleries, villages, gardens and finally the sebkha, a salted depression serving as drainage system.

Salted depressions, or closed basins, are prevalence in the whole Sahara, from the Nile to the Saoura (Gautier 1923, p.39). Some authors interpreted some old sources and concluding that they are former lagoons (Marouf 1980). More recent studies deny this and give more arguments that they remain the same since the Antiquity (Bisson 2003).

The foggara seems to be an endogenous development starting from a dried up source (Cornet 1952). Various particularities reinforce this thesis starting from its climatic and hydrological conditions. Furthermore, its Zenet name, *ifli*, largely in use in the Maghreb Sahara territories while it has various Arabic names such as chegga in Hodna area and khettara in Morocco. According to local tradition, *ifli* means underground channel which gives water while foggara gives in Arabic the same meaning. Given that Berbers are older in the region than Arabs; this suggests that foggara could be the Arabic translation of the Berber name.

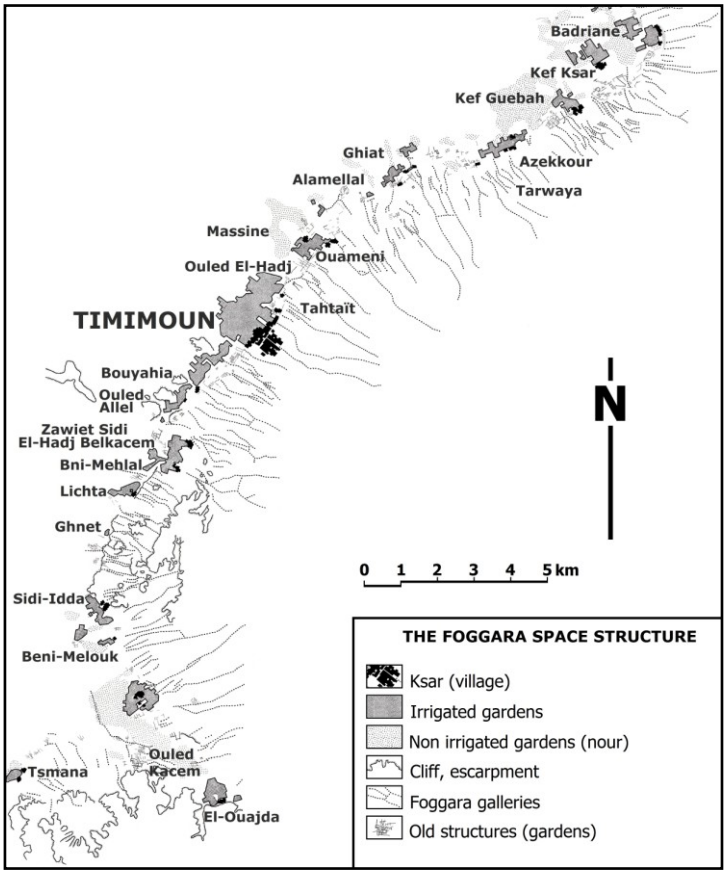

Fig. 3, The foggara space structure at Timimoun and its region.
Prepared from Echallier works (1972)

In Orient, qanat shafts are circular while foggara ones are exclusively rectangular and usually 1.2m length and 0.5 to 0.6 m width as for the gallery. The qanat is dug initially upstream; some wells are dug first as a test in order to identify a mother well which indicates how the gallery would be dug starting from a preliminary calculated point downward. This know-how is quite missing in the Gourara. Galleries advance upstream from its exit point. It lengthens upstream each time one considers it necessary to reinforce flow.

Water distribution is commonly by volume rarely by duration. Water ownership is different from land or palm trees. Water shares are in the basis of a corporation system which organizes foggara management issues and new invests. Water is also at the basis of a local system of Waqf, an endowment ensuring social and religious activities such as mosques, Coranic schools, saints' festivities etc.

Water is divided using a copper plate called *Hallafa* or *Chakfa*, whith a range of holes in different scales. Shares are diverted by a comb called kesria in a range of channels running into gardens. The basic unit has various names according to the region (Mercadier; Rondreux; Salleras 1946); it is *Habba* in North Gourara; *Kherga* in the Auguerout; *Thmen* in Timimoun and *Madjel* in Tuat region. In all cases the unit is divided as in Table 1.

Water shares are recorded in a written document called *Zmam*. It is required by an official called *Bab-n-Zmam* or even *Mqeddem*. The person is always appointed collegially. Each

foggara has its own expert taking care of its proper functioning; it is the Khabir. Shares' measurement is ensured by another expert called *Kyyel* (Measurer) which can cover several foggaras belonging to various oases

Tab. 1. Water subdivision by volume in the foggara shares.

Fractional division	**Division by *Kirat-el-kirat***
1 *Habba* = 24 *Kirat*	1 *Wedjba* = 12 *Kirat-el-kirat*
1 *Kirat* = 3 *Thelt* (third)	1 *Thelt* = 8 *Kirat-el-kirat*
1 *Kirat* = 4 *Rebaâ* (quarter)	1 *Rebaâ* = 6 *Kirat-el-kirat*
1 *Kirat* = 6 *Sudus* (sixth)	1 *Sudus* = 4 *Kirat-el-kirat*
1 *Kirat* = 24 *Kirat-el-kirat*	1 *Thmen* = 3 *Kirat-el-kirat*

Distribution canals are used to be made of hewn stones from a quarry situated often near the oasis. In other oasis, especially in the Erg, channels are stone built with lime; the sand sediments in the canal form eventually with the limestone dissolved in water an impermeable layer that prevents leaks. By the fifties they became in cement; recently they are more likely in plastic tubes. Only combs remain in use, advanced technology couldn't supplant them.

THE ARTESIAN SYSTEM

The artesian system is based on the simple rule to allow underground water under pressure coming to the surface. Artesian wells seem to be very old; the oldest known source is of Ibn-Khaldun describing the digging of a well in the 14th century in the region of Wadi-Righ.

The artesian system is the most appropriate that identify the Lower Sahara (Northeast) from the Ziban region (Biskra) at the foothill of Saharan Atlas to the Wadi-Righ in the south (Ouargla). El-Golea is the more western artesian oasis. Artesian water comes even more from the Terminal Complex aquifer described in figure 1.

Water availability seems more evident; it explains early French interests to enhance water resources in order to consolidate more crops and European permanent presence. The region offers a huge of lakes called *sebkha* or *behour* attesting water abundance.

In Wadi-Righ region wells have from 45 m to 80 m depth. The digging crosses different layers, almost limestone and clay. In order to prevent sand and saltwater, the weak parts are sealed with palm wood frames (Fig. 3). Wells are 0,7 to 1m large (Berbrugger 1862). The digging is a very hard work, so it is always undertook collectively so that no artesian well could be found with one single owner. Water division by duration is the common rule. A network of canals ensures water distribution through the palm tree gardens while other wells supply water for the village.

In artesian system water irrigation has to be drained away from the oasis.. There are two kinds of canals; irrigating canals and draining canals. The first network supply water irrigation for the gardens, the second discharge water after irrigation to a lower area called *Chemoura*.

In the case of Touggourt, where is the most concentrated artesian wells, water drain used to be collected in a main canal called *Hemmala* which goes close to Tebesbest village where it is used to irrigate a great part of its gardens. The result is a double benefit: recuperation of excess water from Touggourt and supply water irrigation to Tebesbest for free.

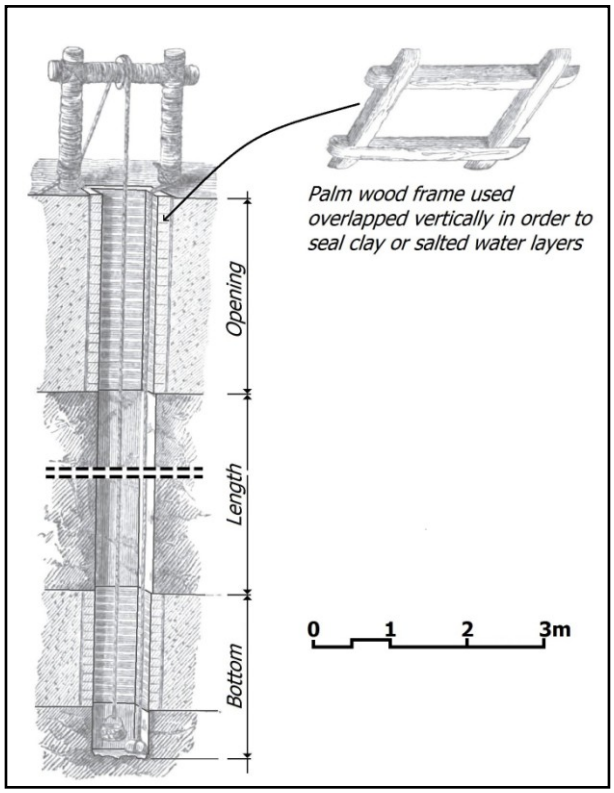

Fig. 3, Longitudinal Section of a traditional artesian well in Wadi-Righ. Prepared from Laurent (1859).

There is a constant need for maintenance given the various challenges targeting its functioning. The infected water can leak through the well; the sand can be carried by artesian water and deposited progressively in the well to seal it completely. A group of divers called *Ghattassin* often undertake to reseal the weak parts or to remove the sand from the well bottom. Water pressure is so high that the diver can die; so they could not make more than three or four round-trip to excavate each time some 10 kg of sand.

Even with maintenance efforts, artesian wells are not as durable as foggaras. They can live more than a century when dug in stoned site without a sand layer or bad waters intermediate aquifer. French administration undertook to introduce mechanized workshops in order to optimize digging operations. In June 19th 1956, the first French artesian well was dug in Tamerna with 60 m depth and a first flow of 3600 l/mn. The event was celebrated a year later by the Imperial Academy by a poesy competition (Chavanne 1858). A huge of artesian wells have been dug in Wadi-Righ, Ziban, El-Golea, Tidikelt, Tuat, and south Gourara but with less success. Some new oases have been created since 1882 by French corporations such as Ourir with 27000 palm trees and Sidi-Yahia with 13500 palm trees.

THE MZAB SYSTEM

The Mzab region is located some 600 km South of Algiers. The area is served by a limestone plateau with 250 to 750 m high. The average rainfall does not exceed 100 mm per year, however the stone plateau, being waterproof and sloping to the South, flows water to the region by a group of rivers: Mzab, Metlili, Seb-Seb, N'sa and Zeghrir. Flows are not permanent but when doing, they run fast preventing both evaporation and infiltration until

getting the Mzab valley. This river network is called in arabic *Chebka*. Water infiltrates the valley up to 55 m depth; the aquifer supplies a group of seven oases which is the capital Ghardaia. The first oases were built downstream; El-Ateuf (1012) and Bounoura (1046).

The basic rule in the Mzab system is to take the biggest benefit from the seasonal floods. Water is diverted into the gardens by canals. Once gardens irrigated, the floods are used to fill the deeper aquifer (Turonian) trough the filling wells; these are particular as they meet the major rock faults making water filling faster. More floods are diverted into the basins dyke to infiltrate the alluvial aquifer (Fig. 4).

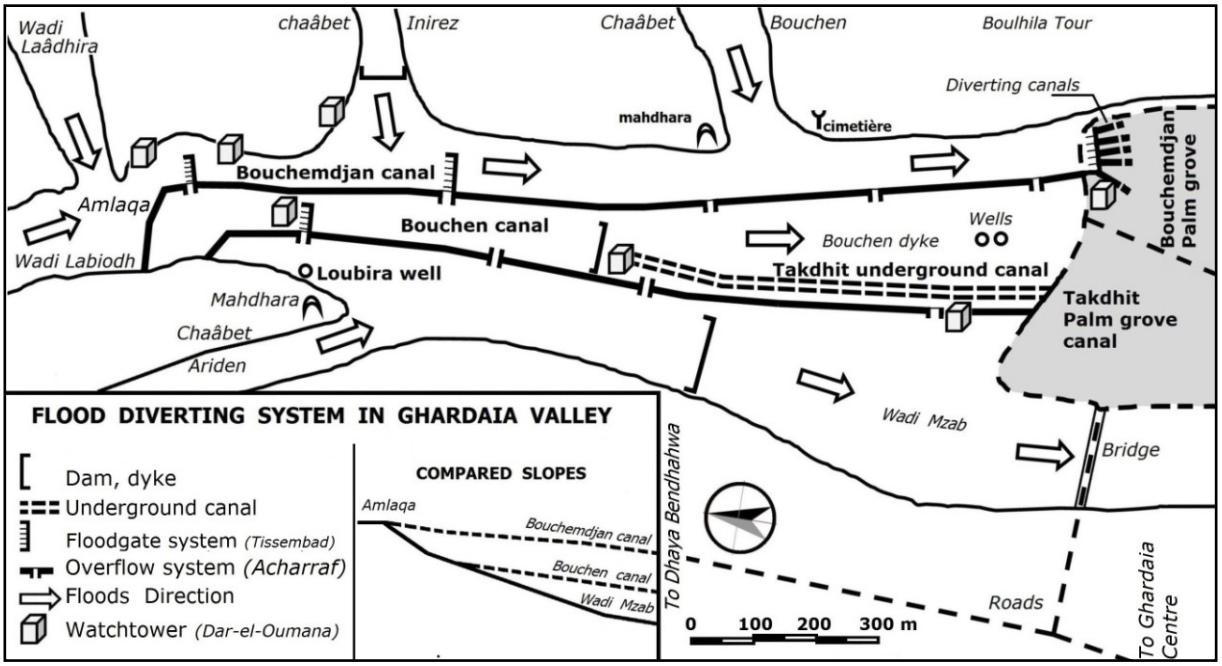

Fig. 4. Ghardaia (Mzab region), Map of the floods distribution system; prepared from the restoration project under the auspices of the Unesco managing structure, the "Office de Promotion de la Vallée du Mzab" (OPVM).

The role of the Mzab wells is to restitute water during the rest of the year. Wells are of three categories. Alluvium wells are short both in depth and water availability; they should give water from six to thirty months and are 20 to 25 meters depth. Permanent wells, called also *Warwara*, catch from the deeper aquifer in the Turonian layer 50 to 55 meters depth (Charlet 1905); they can give water continuously without exceeding a flow limit. The third category is of those wells giving continuously water without flow limits; they are called *Tamehrit*. Some wells of the two last categories serve as filling-wells when they meet major rock faults in depth. They also have a larger bottom room and horizontal galleries dug in various depths in order to reinforce water catchment. Some of these galleries are connected so that they draw an underground network enhancing mutually wells capacity (fig. 5).

As the river flooding is not frequent enough, the Mzab system uses dams, dykes, canals and wells to optimize the floods' use. This is achieved by a direct irrigation when floods happen and a direct filling into the deep aquifer reinforcing its capacity. Canals, dams and dykes are equipped with an overflow system, called *Acharraf*, diverting exceeding water back to the river; this prevents water devastation. They are also equipped with a range of floodgates, called *Tissembad*, to control the flow rate.

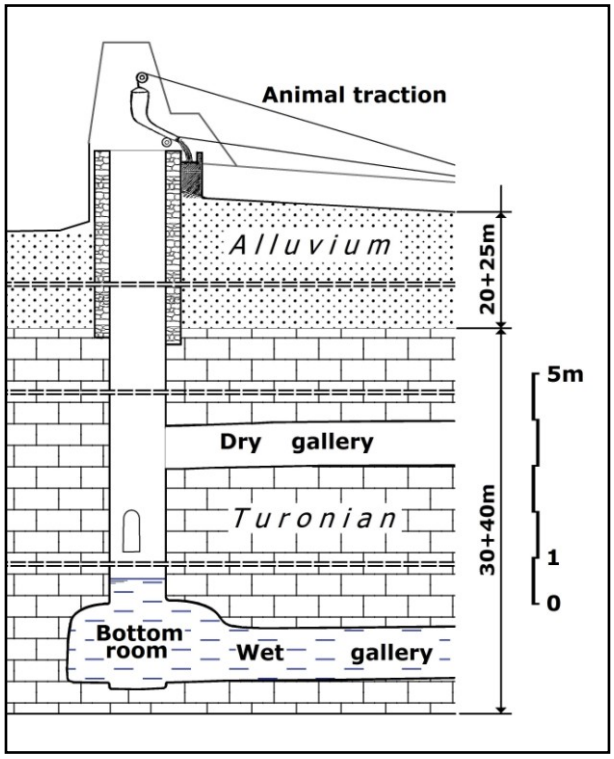

Fig. 5. Cross section showing a basic *Warwara* well with its horizontal galleries and the bottom room.

Mzab wells may give water continuously for both gardens and cities up to seven dry years. The Mzab system may be considered as the most artificial historical hydraulic system in the whole Sahara. This system has founded five continuous cities from Ghardaia upstream to El-Ateuf downstream. The implementation is ruled by the traditional authority called *Azzaba* through a corporation of controllers called *Oumana-Essayl*; they expect the climate changes, expect the rain, ensure coordination and communication using mirror and fire signal system to communicate all the way through by day or by night, especially when advent the floods.

Water division is sequenced. Floods are divided by volume given their short time. Main canals continue through the garden streets serving as canals. Each garden entrance has a calculated hole corresponding to the owner share. Beyond the floods, water comes from well extraction and division is therefore by duration. Due to successive inheritance, division in gardens is always needed; a single well serves a unit garden called Ghaba which is divided into up to twenty parts called Haouza, with an average of 50 palm trees. Each day is divided in 24 units called kharrouba (MOULIAS, 1927); division continues then in smaller subdivision (Tab. 2). The Mzab water division is quite recorded and well codified (Féliu 1908).

Table 2. The Mzab wells Water subdivision.

Fractional division			**Numerical division**		
1 *day/ night*	=	24 *Kharrouba*	1 *Kharrouba*	=	1 Hour
1 *Kharrouba*	=	8 *Thmen*	1 *Thmen*	=	7,5 Minutes
1 *Thmen*	=	3 *Mouzouna*	1 *Mouzouna*	=	2,5 Minutes
1 *Mouzouna*	=	30 *Dirhem*	1 *Dirhem*	=	5 seconds

Units are called white or black due to day or night sharing. In practice, only *Kharrouba* units are applicable, the others serve for calculation. Daily shares are gathered up to reach a quarter day and given in one time. Time shares are defined shadow measurement by day and stargazing by night.

The Mzab valley is surrounded by artesian region such as Oued Righ at east and El-Golea at southwest. Efforts were spent in vain before and during French colonization to prospect artesian aquifer. The urban and agricultural complex of Mzab valley constitutes a very particular human achievement as an original territory combining environment and culture. This allowed classifying the Mzab valley as a world heritage since 1982.

DISCUSSION

Saharan settlements have been prospering for a very long time according two major reasons: local irrigated agriculture enabled by appropriate hydraulic systems to ensure subsistence; trade exchanges have kept relationships with the surrounded civilizations in both African and Mediterranean sides. The exchange completes oasis life needs. Most prosperous oases are those having continuous resources without any need to extraction efforts. It is the case of artesian and foggara systems; important maintenance efforts are however required.

Tab. 3. Compared main characteristics of the three major water systems in Algerian Sahara.

Water system	**Foggara**	**Artesian well**	**Mzab system**
Geography	Tademait plateau	Oued Righ	Mzab valley
Urban morphology	Linear-orthogonal	Various thanks to topography	Modular units (pentapole)
Organization	Corporation	Cooperative	City community
Water origin	Fossil aquifer, very limited recharge	Fossil aquifer with limited recharge	Aquifer recharged by seasonal floods
Water division	Volume	Duration	Mixed
Water flow rate	Steady	Steady	Fluctuating
Major concerns	Gallery maintenance	Drainage	Managing floods

Water division depends of water availability or historical conditions. Artesian flow is so important and steady that it can be shared by duration. The foggara water shares are smaller and need to be distributed by volume allowing water availability to irrigate vegetables in short occurrences. Most rational is the mixed Mzab system; floods occur rarely and suddenly so that they must be shared in volume up to gardens while the well extraction could be shared in duration. These corresponding systems used to follow their genuine distribution for centuries.

Each major system supplies from the underground water. In the Mzab case, they compensate the lack of fossil aquifer by diverting the floods directly into the Turonian aquifer. Nevertheless, the Mzab system presents more evident weakness due to fluctuating rainfall.

In both foggara and Mzab systems, there is a close relation to the urban morphology. Foggaras draw a linear development from the gallery up to the draining area, the oasis is often a serial development following the orthogonal direction; the morphology presents therefore a linear orthogonal frame. In the case of Mzab system, water organization dictates the feature of modular unit which is the city; beyond that scale, more units are needed. However in the case

of artesian system, the major concern is to drain water irrigation due to feeble slopes. Hence, the priority is to identify a lower point to direct the flow. Gardens are tehrefore thin and very long in order to allow each garden having its drain share. The village location always follows the way the garden morphology is managed.

CONCLUSION

Water systems used to be central in oasis life. Water is the first and the most important wealth. Water challenges are directly linked to community life; water is always at the basis of the ecosystem.

Each of these major systems is not yet recognized as world heritage. The Mzab valley is a world heritage; it has not been recognized due to its genuine hydraulic system even if it has been considered recently as a particular aspect of an endangered heritage.

More recently, interest raises to reinforce knowledge and preserve these systems as a heritage; meaning that they could no more remain central in the oasis life. With more threats, the public awareness will steadily bring more care to their genuine aspects and may allow new insights in the way we may deal with environment and natural resources.

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